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# Arches and Burners for Oil-Fired Maple Sap Evaporators

Agricultural Research Service
U. S. DEPARTMENT OF AGRICULTURE

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# FOR OIL-FIRED
# MAPLE SAP EVAPORATORS

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## ABSTRACT

A basic design, including dimensions and suggested materials, is given for the construction of arches and their contained combustion chambers for the evaporation of maple sap. Also included are burner nozzle angles, methods for calculating the size of oil burners for different sizes of evaporators, and the position of the burner with respect to the arch.

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# ARCHES AND BURNERS FOR OIL-FIRED MAPLE SAP EVAPORATORS

by

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## INTRODUCTION

Age-old tradition indicates the use of wood for fuel in firing maple sirup evaporators. With the present shift to larger operations and to the central evaporator house where sap is purchased and where the evaporator may run daily for 24 hours during peakloads, it is essential that a fuel be found that can be called on for longer steady use with a minimum labor requirement. Operators have turned to many combinations of fuels, such as used crankcase oil dripped on wood; coal, usually bituminous, used with wood; natural gas; and heavy heating oils. Domestic fuel oil has proved to be the most satisfactory.[2]

The advantages of using oil as the heat source for the evaporation of maple sap to sirup are numerous. Chief among these are: (a) Operation of the oil is automatic, therefore, it does not require the use of a fireman; (b) Oil provides a steady uniform heat, which is desirable for the production of high quality sirup; (c) Oil is clean; therefore it aids in better housekeeping and sanitation in the evaporator house; and (d) the cost of oil in terms of British thermal units (B.t.u.) is about the same as for wood but without the cost of a fireman, its operation is less.

The disadvantages of using oil as the fuel source, while few, are nevertheless important: (a) The initial cost (capital investment) of oil burners is high; (b) the burners require a special arch (firebox), which in a new installation is not necessarily more expensive than the conven-

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[2]Phillips, G. W. Macpherson, and Homiller, Richard P., Oil firing for the maple sirup evaporator. U.S.Dept. Agr., Bur. Agr. Indus. Chem., AIC-358. June 1958.

tional wood-burning arch; and (c) oil burners do not provide a use for the cull trees that must be removed each year from a well-managed sugar bush.

## OIL BURNERS

In oil burners, a number of pertinent facts must be observed. First and most important, oil burns as a ball of flame--radiant heat--in only a relatively small space; while wood burns with a luminous (long fire path) flame--convection heat--where hot flue gases pass throughout the length of the evaporator, including the area under the flue and under the sirup pan. Secondly, of the two forms of heat transfer utilized in a sap evaporator, radiant heat accounts for approximately 80 percent of the heat transferred to the liquid, whereas convection heat supplies approximately 20 percent of the effective heat. Therefore, to make use of the radiant heat from the oil fire, the ball of burning oil must illuminate the entire under surface of the pans. This necessitates the proper positioning of the ball of burning oil, including eliminating any obstructions that will prevent this illumination of the entire under surface of pans. This requirement will be met only through the proper design of arches made for the burning of oil as fuel.

A wood-burning arch cannot be successfully converted to an oil-burning arch without major changes. The principal fault of such a conversion is that the slope of the wood-burning arch behind the firebox is such that it does not permit illumination of the underside of the sap or flue pan by the ball of oil fire. Consequently the sap will not boil in the flue pan at a sufficiently rapid rate, if at all.

### Burner Size

The size of burner to be used is determined by two factors: (1) The size (area) of the evaporator, that is, its length and width (the vertical area of the flues has a minor effect), and (2) the number of gallons of sap to be evaporated per hour. If the rated capacity of the evaporator in gallons of sap per hour is known, it can be divided by 13 (the approximate number of gallons of water evaporated per hour by 1 gallon of oil) to obtain the size of the burner (g.p.h.--gallons of oil per hour) required for a specific evaporator.

THE RATED CAPACITY OF AN EVAPORATOR FOR WOOD FUEL CANNOT BE ACCURATELY EQUATED TO THE BURNING OIL. This method of calculation may indicate a burner that is too large (g.p.h.). However, this is not serious since the amount of oil burned per hour can be changed (within limits) by merely changing the burner nozzles.

CAUTION

To prevent damaging the pan due to firing with an oversize burner, it is recommended that for the first trials a nozzle size 20 percent smaller than that indicated by the above calculation be used. The burning rate (nozzle size) can then be increased as experience indicates.

A safer method for determining burner size is to divide the surface area, length times width, by 5. Thus, a 5 feet by 12 feet evaporator would require a 12 g.p.h. nozzle $(\frac{60}{5})$.

## Type of Burner

With but few exceptions, high-pressure type oil burners that use No. 2 oil are recommended. These are available with different nozzle sizes to meet the needs for all evaporator sizes. Their lower costs offset any advantage gained by use of burners that use the heavier grades of oil.

## Number of Burners Per Arch

Only one burner is required for each evaporator. This single burner must be correctly positioned under the evaporator and the dimensions of the combustion chamber meet certain minimum dimensions. The use of a single burner will reduce the capital investment and installation costs. For example, an evaporator requiring 12 gallons of fuel per hour, if supplied by a single burner, would require burner cost and installation of approximately one-half that required if two 6-gallon per hour burners were used. In addition, the two smaller burners will require more servicing and attention than will the larger one.

To successfully use one burner, however, it must be mounted a sufficient distance below the bottom of the pan so that the radiant heat will be effective across the full width of the pan. If the arch is so constructed as to make it impossible to mount a burner the required distance below the pan (table 1), two or more smaller burners, mounted horizontally (side by side) to insure heating the pan its full width, must be used. In other instances, especially with wood-fuel arches that have been converted for the oil-burners, if the slope of the arch is not modified so that the under surface of the flue pan can be illuminated by the ball of fire (fig. 1), the rate of boiling will be too slow. It is possible that boiling will not occur. To compensate for this, a supplementary firebox is constructed under the flue pan and another expensive burner may be mounted here but with doubtful effect. If the building is essentially airtight, air access for burner combustion must be provided.

## Nozzle Tip

For evaporators with lengths spproximately twice the width, the nozzle tip should be 80°. For evaporators with lengths greater than twice their width, the nozzle tip should be 60°. Irrespective of the type or angle of the nozzle tip, the burner must be adjusted so that the correct amount of air is fed along with the atomized oil to insure complete combustion. This is best checked with a flue gas analyzer. However, a check of the flue gases is helpful. A sooty smoke indicates incomplete combustion (insufficient air to the burner).

## The Arch and Combustion Chamber

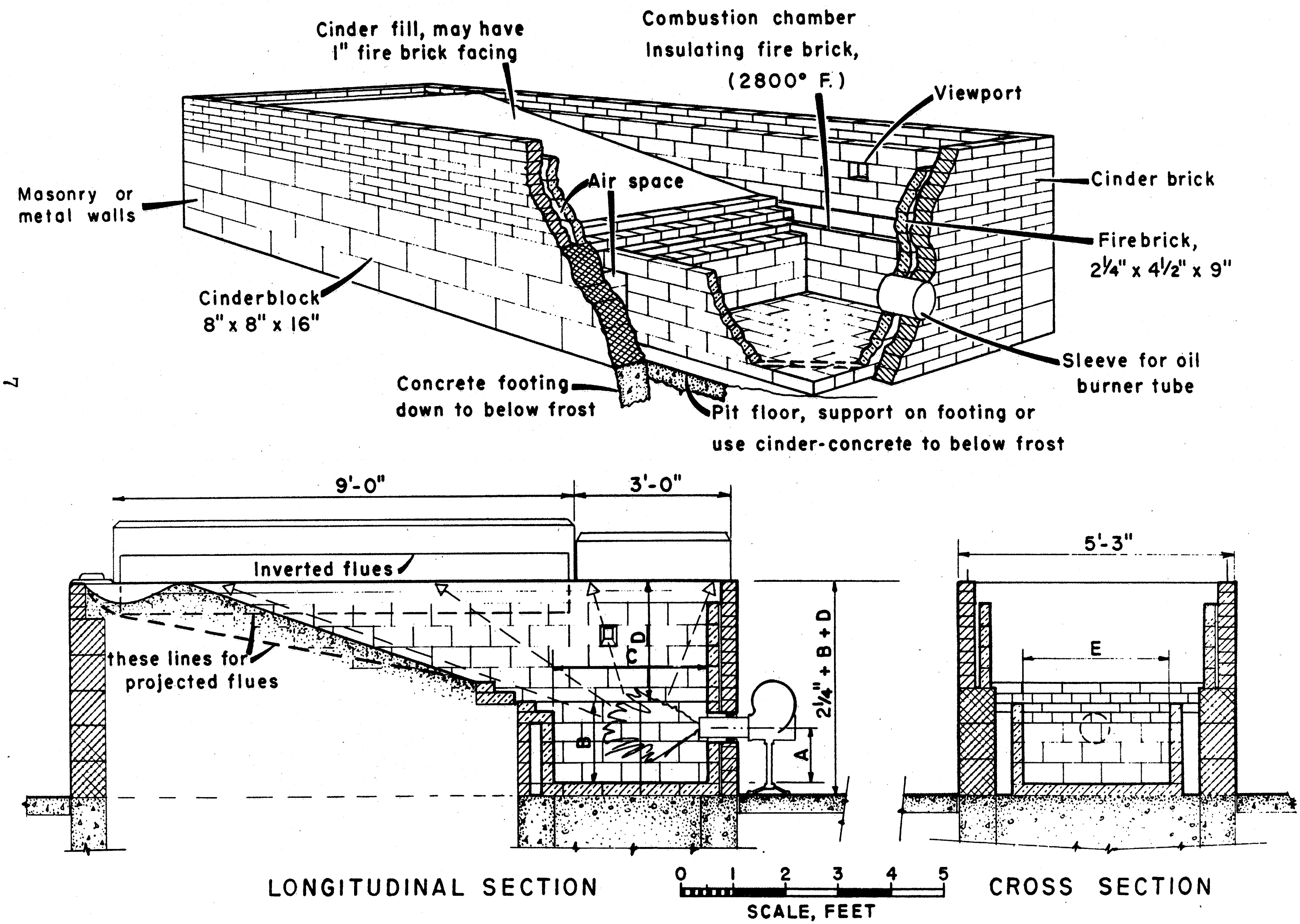
The arch, or fire chamber, for oil fuel also serves as a support for the evaporator pans and contains the combustion chamber and the flue for the hot gases. The arch should be so located in the evaporator house as to provide an adequate working area around it with sufficient room for installing of supplemental arches necessitated by expansion of the operation. The arch need not be centered in the building but may be placed at one side of the evaporator house. The concrete footings for the arch should be on gravel and extend below the frost line. The exterior wall of the arch may be built of all-masonry cinder block or brick or both, may be built on the site, or the arch may be partly prefabricated and supplied with exterior walls of sheet metal on a cast iron and steel frame. In either case only quality materials are recommended. The arches must conform to certain minimum dimensions and the materials for the interior construction must be similar for both.

## Dimensions

The size (length and width) of the arch is determined by the size of the evaporator. Its front walls provide support for the pans and its side and rear walls must provide for mounting the base of the flue-gas stack and for supporting the pans. Figure 1 shows a masonry arch for a 5 feet by 12 feet evaporator (9 feet flue pan and 3 feet flat pan). The outside walls are of cinder block with the top section of 4-1/2 inch bricks that provide a 2-inch supporting surface for the pans and that project 1-1/2 inches beyond the pans. If the arch is made to the exact outside dimensions of the pans, the supporting wall--if made of cinder blocks--would cover too much of the under pan surface (3-1/2 inches on all sides). This would cause a large loss of heating surface.

The height of the arch will be governed by the size of the combustion chamber, which in turn is governed by the size of the burner (table 1), and the size of the evaporator. In figure 1 for the 5 feet by 12 feet evaporator, the height of the arch is 48 inches above floor level. The height of the pans 48 inches or more above the floor level is desirable,

# ARCH AND COMBUSTION CHAMBER FOR OIL FIRED EVAPORATOR



because this permits the use of gravity flow in handling the sirup in successive operations. If the arch, however, causes the pans to be too high, especially when multiple evaporators are used, a catwalk can be installed, or the combustion chamber part of the arch and burner can be built in a pit. If a pit is 8 inches deep, one course of cinder blocks above floor level is eliminated; if it is 16 inches deep, two courses of cinder blocks are eliminated.

## Firebox and Combustion Chamber

The "firebox" is the entire open space enclosed by the arch under the pans. Better results will be obtained if it contains a combustion chamber (fig. 1). The function of this chamber is to (a) provide a hot radiating surface and (b) to utilize the hot, incandescent surfaces to vaporize and insure complete combustion of the oil. The size of this combustion chamber for maximum efficiency must conform to minimum dimensions which are related to the nozzle size of the burner. These are given in table 1. A rough rule of thumb relationship between combustion chamber and nozzle size is that there should be a floor area of 90 square inches for each gallon per hour of rated nozzle capacity. The distance between the top of the combustion chamber and the bottom of the pans (top of arch), dimension D of fig. 1, is important for two reasons: (1) The burning ball of oil should be sufficient distance below the "cold" pan surface to prevent corrosive deposits on the underside of the pan and (2) the ball of fire must be located far enough below the pan so that the acute angle of radiation from the apex (ball of fire) to the extreme sides of the pans is kept to a minimum. The minimum distance for D is given in table 1. If the ball of fire is too close to the pan, there is insufficient space between pans and top of combustion chamber and the angle of radiation becomes too great resulting in uneven heating across the width of the pan. Localized overheating directly over the fire occurs. This can only be compensated for by using more than one burner mounted horizontally.

## Construction of the Arch and Combustion Chamber

Figure 1 shows suggested materials that may be used for the construction of the all masonry arch. In an arch made of sheet metal, the combustion chamber must be built of insulating fire brick with the remainder of the arch lined with hard firebrick. The combustion chamber, in either arch, is free standing within the arch and is constructed of insulating fire-brick. It is separated from the exterior wall of the arch by an airspace to allow for expansion of the heated bricks. While figure 1 shows the firebrick walls constructed in a "rowlock stretcher" manner (bricks laid on their 2-inch face), the same bricks laid on their "natural bed", i.e. on their 4-inch side will be stronger. The natural bed construction requires twice as many bricks, but because of a longer life expectancy,

TABLE 1.--Inside dimensions of combustion chamber and stack diameters

| Burning rate (gal. oil per hr.) | Dimension "A" (in.) | Dimension "B" minimum height (in.) | Dimension C, length for nozzle angle of 60° | Dimension C, length for nozzle angle of 80° | Dimension "D" (in.) | Dimension E, width for nozzle angle of 60° | Dimension E, width for nozzle angle of 80° | Approximate floor area (sq. in.) | Minimum stack diameter (in.) |
|---|---|---|---|---|---|---|---|---|---|
| 5 | 9 | 18 | 25 | 22 | 19 | 18 | 21 | 450 | 10 |
| 6 | 9 | 18 | 27 | 24 | 19 | 20 | 23 | 540 | 10 |
| 7 | 10 | 19 | 29 | 26 | 20 | 22 | 25 | 630 | 10 |
| 8 | 11 | 19 | 30 | 28 | 20 | 24 | 26 | 720 | 12 |
| 9 | 11.5 | 19 | 32 | 29 | 20 | 25 | 28 | 810 | 12 |
| 10 | 12 | 19 | 33 | 31 | 20 | 27 | 29 | 900 | 12 |
| 12 | 13 | 20 | 36 | 34 | 20 | 30 | 32 | 1,080 | 12 |
| 14 | 14 | 21 | 39 | 36 | 20 | 33 | 35 | 1,260 | 14 |
| 16 | 15 | 22 | 41 | 39 | 20 | 35 | 37 | 1,440 | 14 |
| 18 | 16 | 23 | 44 | 41 | 20 | 37 | 40 | 1,620 | 16 |
| 20 | 17 | 24 | 47 | 43 | 22 | 39 | 42 | 1,800 | 18 |
| 22 | 18 | 25 | 49 | 45 | 22 | 41 | 44 | 1,980 | 20 |
| 24 | 19 | 25 | 51 | 47 | 22 | 43 | 46 | 2,160 | 20 |

"A"--Height of burner sleeve. The dimension from combustion chamber floor to center of burner sleeve.
"B"--Height of combustion chamber side walls. The dimension from floor of chamber to top of side walls.
"C"--Depth of combustion chamber. The dimension between the front and rear walls.
"D"--Height of arch walls above combustion chamber side walls. The dimension from top of combustion chamber side walls to top of arch.
"E"--Inside width of combustion chamber. The dimension between the side walls.

it may offset higher initial cost. Irrespective of the manner in which the firebricks are laid, the inside dimensions of the combustion chamber must conform to those given in table 1. The mortar used must be that recommended by the manufacturer of the firebrick. To strengthen the thinner constructed wall, the front corners of the combustion chamber are cut across to shorten the front and side walls (fig. 1). For the same reason there is an air space between the hard firebrick liner and the exterior cinder brick walls of the arch. The fill, between the combustion chamber and the rear of the arch, must be of a nonpacking material such as cinders. The walls other than those of the combustion chamber should be of cinder blocks and cinder brick rather than of concrete because of their more uniform thermal expansion. Concrete, because of its heterogeneity, tends to disintegrate more rapidly on successive heating and cooling.

Note: To prevent damaging the combustion chamber firebrick, caused either by the heat shocks resulting from the sudden very high temperature of the oil burner flame or from moisture or frost in the bricks, the combustion chamber should be warmed prior to ignition of the oil burner. Warming can be done by use of a 150-watt light bulb or other type of heater placed in the chamber. The chamber should be covered with a sheet of flexiboard or other insulating material to retain the heat. The chamber should be warmed by heating it continuously for at least a week in advance of its first use.

## Stack Size

Since the oil burner is operated under forced draft the height and diameter of the flue stack need not be as great as when wood is the fuel. The stack size, cross sectional area (diameter) is governed by the size of the oil burner (g.p.h.). Table 1 gives suggested diameters.

## Multiple Arch Installation

When only one arch is used, the recommended procedure is to use a complete evaporator, flat pan, and flue pan. However, the flue pan should be at least two-thirds of the total length of the evaporator. The flat pan serves as the semifinishing pan in which the Brix of the sap is raised to 55° or 60°. The concentrated sap liquor should be removed from the evaporator and the final stage of the evaporation completed in a finishing pan. The sap can be concentrated to sirup in the evaporator, but this practice is not advised.

To increase the capacity of the evaporator in gallons of sap evaporated per hour, additional arches and pans are added. Each additional arch will be equipped with a flue pan only and will be installed ahead of, and in series with, the complete evaporator (fig. 2). The supplemental flue

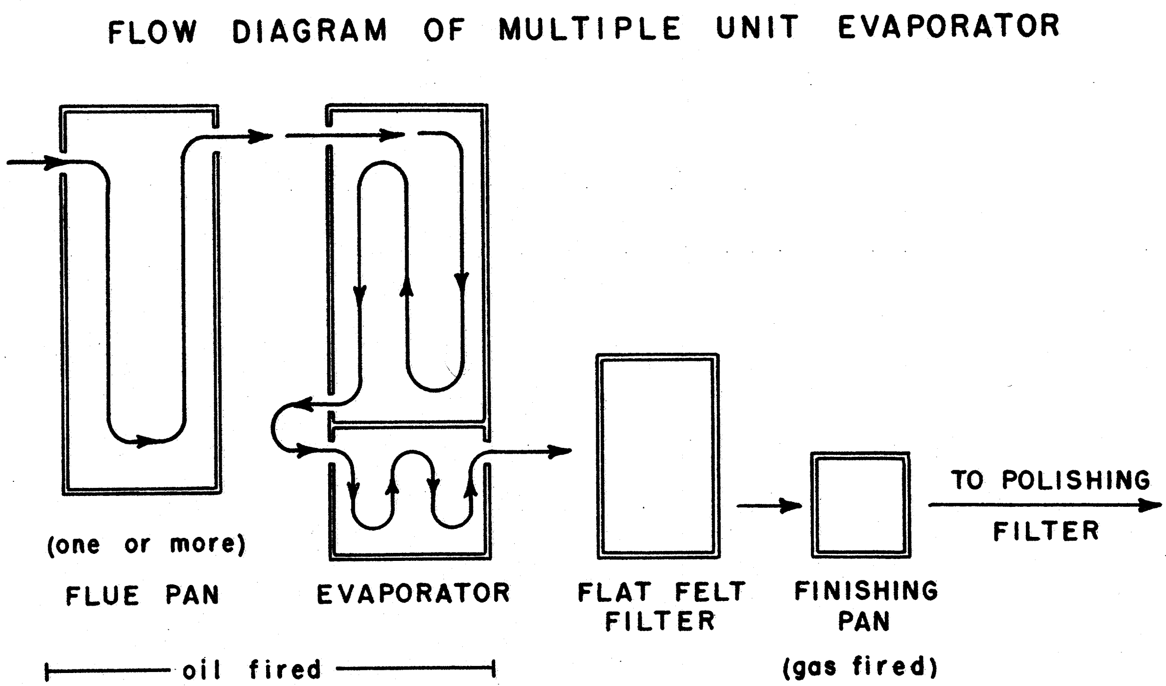



Figure 2--Flow diagram of multiple unit evaporator

pan arches are constructed in exactly the same manner as the one supporting and heating the complete evaporator. By connecting the supplemental flue pans in series with the evaporator, there will be only one point at which the raw sap is fed and one point at which the partly evaporated sap or sirup is removed for transfer to the finishing pan or bottling tank. In the multiple unit assembly the flat pan of the evaporator continues to serve as the semifinishing or finishing pan.

## DISCUSSION

A study of the use of oil as fuel for the evaporation of maple sap in an open pan evaporator was reported by Strolle and coworkers.[3] They showed that commercial maple sap evaporators have an efficiency when fired with oil of 66 to 74 percent. Their data were obtained by using a smaller than average evaporator. Larger evaporators would be expected to have slightly greater efficiencies. These efficiencies compare favorably with

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[3]Strolle, Eugene O., Cording, James, Jr., and Eskew, Roderick K. An analysis of the open-pan maple-sirup evaporator. U.S. Dept. Agr., Agr. Res. Serv., ARS 73-14, October 1956.

commercial steam generating plants for which a combustion efficiency of 80 percent is considered good. The efficiencies obtained by Strolle and coworkers[3] in evaporating 45 to 50 gallons of 3° Brix sap to standard denisty sirup are given in table 2.

TABLE 2.--Oil-fired evaporator efficiencies obtained with the experimental evaporator.

| Sap evaporated G.p.h. | Oil Burned G.p.h. | Efficiency percent |
|---|---|---|
| 45 | 3.9 | 74 |
| 50 | 4.7 | 69 |
| 55 | 5.3 | 66 |

These data indicate that the efficiencies fall off with increased rate of sap flow (gallons of sap evaporated per hour) and that oil costs per hour rise markedly. However, from further calculations and rough extrapolations the data in table 3 were obtained.

TABLE 3.--Extrapolated efficiencies

| Efficiency Percent | Sap G.p.h. | Sirup G.p.h. | Oil G.p.h. | Oil Cost per gal. sirup Dollars | Time to Evaporate 550 gal. sap Hr. |
|---|---|---|---|---|---|
| 59.6 | 65 | 2.36 | 6.7 | 0.43 | 8.5 |
| 62.6 | 60 | 2.18 | 6.0 | .41 | 9.2 |
| 66 | 55 | 2.00 | 5.3 | .40 | 10.0 |
| 69 | 50 | 1.82 | 4.7 | .39 | 11.0 |
| 74 | 45 | 1.64 | 3.9 | .36 | 12.2 |

These data show that (a) more sirup is produced per hour with increased g.p.h. of fuel burned, thus reducing labor cost, and (b) the increase in fuel cost per gallon of sirup made is slight. This small increase in fuel cost is more than compensated for by the improvement gained in the grade of the sirup obtained and by the reduction in evaporation time (labor cost).

The maximum or 100 percent efficiency that could, theoretically, be obtained from an oil-fired evaporator is one that, in theory, would utilize all of the B.t.u.'s of a gallon of oil. This heat would be used to raise the temperature of the feed sap to its boiling point and then to vaporize the sap water to steam. Assuming the temperature of the sap to be 35° F. and its boiling point temperature to be 210°, the heat (B.t.u.) required to evaporate the 34.4 gallons of sap of 2.5° Brix to yield 1 gallon of standard density sirup can be calculated. Knowing the B.t.u.'s of No. 2 fuel oil, the number of gallons of oil required to produce this gallon of sirup at 100 percent full efficiency is 2.2 gallons. Since no oil burner is 100 percent efficient, and oil-fired evaporators are only 60 to 75 percent efficient, the fuel requirement per gallon of sirup will be 3+ gallons of oil.

To measure the efficiencies of different burners, arches, and evaporators so data can be obtained, a number of factors must be carefully observed, recorded, and used in the computations. These are:

1. <u>The Brix of the raw sap</u>: For example, only one-half as much water is evaporated from a 3° Brix sap as that from a 1-1/2° Brix sap to make standard density sirup. Therefore, other things being equal, it would require only one-half as much oil to make sirup from 3° Brix sap as from 1-1/2° Brix sap.

2. <u>Temperature of sap</u>: The temperature of the sap as it enters the evaporator must be noted, because a great deal of heat is required just to heat the sap from its storage temperature up to its boiling temperature. Therefore, the warmer the sap, the less oil will be used to heat it to boiling.

3. <u>The Brix of the finished sirup</u>: All too often the exact Brix of the sirup is not considered in making efficiency studies. Yet a difference of only a few tenths of 1° Brix will have a pronounced effect on the number of gallons of sap that were evaporated to produce the sirup.

The cost of the fuel oil can be kept low by contracting for it by competitive bidding so that lowest commercial rates will be obtained.

Most producers for purposes of their cost accounting records will find that merely dividing the number of gallons of sirup made by the number of gallons of oil burned will give the fuel costs per gallon of sirup. This data in no way should be construed as an estimate of the efficiency of the oil burner installation.

The following table indicates that one cord of wood is equivalent to approximately 175 gallons of oil:

BRITISH THERMAL UNIT

| Per Gallon | Per cord (4 by 4 by 8 feet) | | |
|---|---|---|---|
| No. 2 Fuel Oil | Maple | Beech | Hickory |
| 139,400 | 22,800,000 | 20,900,000 | 24,800,000 |

Based on 15 cents per gallon of oil, the wood would have an equivalent value of 26 dollars per cord. These values are based on sound, well-seasoned wood. The efficiencies obtained using wood fuel are dependent upon many variables, such as condition of the wood, size of the individual pieces, how it is fired, condition of the fire, and stack height.

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